Before The
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Amendment of the Commission's Rules to	)	WT Docket No. 04-435
Facilitate the Use of Cellular Telephones and Other	)	
Wireless Devices Aboard Airborne Aircraft	)	

To: The Commission

<u>COMMENTS OF QUALCOMM INCORPORATED</u>

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SUMMARY

QUALCOMM Incorporated ("QUALCOMM") is a leading developer and supplier of digital wireless communications products and services and is the innovator of code division multiple access ("CDMA"), a technology that has become the world standard for the wireless communications industry.

QUALCOMM is an original member of RTCA Special Committee 202. The RTCA, Inc, acting in its capacity as a Federal Advisory Committee, is actively assisting the Federal Aviation Administration ("FAA") through Special Committee 202 ("SC-202") to develop guidance with regard to the use of portable electronic devices ("PEDs") and transmitting PEDs ("T-PEDs") on board carrier aircraft. Phase 1of SC-202's work has been completed, and Phase 2 of SC-202's activities, which are focused on mobile phone and picocell technology, will extend through the end of 2006.

It is through our participation in SC-202 and interaction with other industry groups that led QUALCOMM to engage in a program of development, analysis, and testing to assess the potential for mobile phone interference with aircraft systems and subsequently to determine the feasibility of an airborne mobile phone service through use of an on board picocell. In the picocell concept, transmitting wireless devices on an aircraft would communicate to and from the aircraft mounted picocell, which would connect to the ground through a licensed air to ground link. QUALCOMM understands that the FCC's focus is on whether an airborne mobile phone service will cause harmful interference to terrestrial mobile phone networks. QUALCOMM has also studied that issue in its testing and analysis.

QUALCOMM has completed its initial research using CDMA technology as the baseline cabin service. However; QUALCOMM has a program underway to evaluate dual technology

services using GSM and CDMA technology. There are a number of other companies who have been evaluating GSM airborne services in parallel with QUALCOMM's CDMA program and so we will defer to those companies for the assessment of a GSM baseline service. It should be noted that due to the fragmented spectrum ownership in the U.S. in the Cellular and PCS bands, one terrestrial carrier in any given geographic region may offer CDMA service on a specific set of channels, but another carrier offers TDMA, GSM, or WCDMA (UMTS) service on the same channels in a different geographic region. As a result, any airborne picocell system, independent of the technology used, whether it is CDMA, GSM, TDMA, or WCDMA (UMTS), will need to comply with the interference thresholds for all terrestrial based networks and all air interfaces operating in the Cellular and PCS bands.

In these Comments, QUALCOMM presents a summary of the testing and analysis that it has completed to date, highlighting the design considerations for an in-cabin mobile phone network and the potential impact of such a network to the terrestrial mobile phone services. QUALCOMM has conducted testing to evaluate the impact that an airborne CDMA wireless network may have on terrestrial Cellular and PCS wireless networks. In-cabin CDMA wireless networks are designed to cover the aircraft cabin only. Therefore, any signal detected outside the aircraft cabin is referred to as signal leakage. This leakage could come from both the picocell base station and the phones operating within the aircraft cabin under picocell network control.

In addition to the picocell to which the mobile devices on the plane would connect and the air to ground link to which the picocell would connect, there is a third element to the design of an airborne mobile service, and that is the control mechanism that ensures that the mobile phones authorized for use on the airborne picocell network do indeed connect to that network while airborne, and those phones that are not authorized for connection to the airborne network are controlled to prevent transmission. Although a number of proposals are circulating for a "control mechanism" it is QUALCOMM's view that this is an area that requires further research and potentially collaboration between terrestrial carriers in recognizing the aircraft as a "new" network.

QUALCOMM acknowledges that more analysis and testing is required in order to fully assess the impact of the airborne picocell network to the ground networks. This is particularly true when considering dual technology airborne systems, e.g. CDMA and GSM picocells. Further analysis and testing should be performed jointly with the terrestrial carriers. As the licensees of the spectrum, they are best positioned to assess interference based on their ground network design and capacity/coverage planning.

The test results to date show that the use of mobile phones and other transmitting devices on a plane via an onboard CDMA picocell will result in some level of interference being radiated towards the terrestrial networks. The interference threat is greater when considering other wireless technologies that do not have the minimum output power floor of CDMA based devices[1] . QUALCOMM strongly believes that each terrestrial carrier should be permitted to decide for itself whether to accept such interference in exchange for the revenue that would be generated from the subscribers using their wireless devices on the plane. QUALCOMM has always opposed involuntary overlays or underlays—the notion that the Commission would authorize non-licensees to gain free access to a carrier's licensed spectrum. It is very important that the onboard use of wireless devices not be authorized that way. Each carrier should decide for itself whether it wants to accept any elevation of the noise floor on its network. If a carrier

[1] CDMA based devices power control to a minimum output power of -50 dBm. GSM based devices power control to a minimum output power of 0 dBm.

decides not to do so, it should not have interference from mobile phones on planes injected into its spectrum and its network by Commission fiat.

The Commission is also considering the use of Cellular radio spectrum for the air to ground link. Although Qualcomm has not conducted any tests of such a system, we believe that the interference associated with a direct air to ground link using cellular frequencies will be significant. We therefore believe that as with picocells, terrestrial carriers should be permitted to decide whether and how to implement such as system for planes over flying their licensed areas and make tradeoffs between new revenue from "air to ground" services and accepting interference in the terrestrial service (which would result in reduced service levels and capacity).

Furthermore, QUALCOMM proposes that the spectrum bands authorized by the Part 24 (1900 MHz band PCS), Part 27 (1700/2100 Advanced Wireless Services) and Part 90 (iDEN / SMR) technical rules should be considered collectively with Part 22 (800 MHz "Cellular") in all subsequent rules pertaining to the use of mobile phones on aircraft, as these all operate using similar looking consumer equipment, and are considered by the general public under the same generic terminology “Cell Phones.” The comments provided by QUALCOMM apply to Wireless Wide Area Network (W-WAN) devices using the Cellular and PCS frequency bands. Such devices include much more than just mobile phones—devices such as Blackberrys, WWAN-enabled laptops (i.e., laptops using PC cards to access wireless data service over the Cellular and PCS bands), and PDAs.

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In the matter of Amendment of the Commission's Rules to Facilitate the Use of Cellular Telephones and Other Wireless Devices Aboard Airborne Aircraft	))))))	WT Docket No. 04-435

To: The Commission

COMMENTS OF QUALCOMM INCORPORATED

QUALCOMM Incorporated ("QUALCOMM"), by its attorneys, hereby submits its Comments in the above-captioned proceeding initiated by the Commission in its Notice of Proposed Rule Making, FCC 04-435, released February 15th 2005, ("NPRM") on the issue of whether the Commission should authorize the airborne use of mobile phones and other devices using Cellular spectrum, regulated in the Part 22 of the Commission's Rules.

I. Background

QUALCOMM is a world leader in developing innovative digital wireless communications products and services based on the Company's patented Code Division Multiple Access ("CDMA") digital technology. The Company's business areas include CDMA chipsets and system software; technology licensing; the Binary Runtime Environment for Wireless™ (BREW™) applications platform; Qchat™ push-to-talk technology; Eudora® e-mail software; and satellite-based systems, including portions of the Globalstar™ system and wireless fleet management systems, OmniTRACS® and OmniExpress®. QUALCOMM owns patents that are essential to CDMA wireless telecommunications standards that have been adopted or proposed for adoption by standards-setting bodies worldwide

II. <u>Introduction</u>

When considering the system design of an airborne mobile phone network via picocells, several crucial parameters must be evaluated:

1. Interference from terrestrial systems to airborne picocell networks
   - Signals from multiple phones and base stations on the ground penetrate the aircraft cabin with varying amplitudes, depending on the altitude and position of the aircraft relative to the ground networks
2. Propagation and fading margin within the cabin
   - What is path loss model governs transmissions between a picocell antenna and a passenger mobile phone?
   - Reflections within the cabin randomly arriving in phase and out-of-phase result in up and down fades
3. Aircraft penetration loss
   - What level of shielding does the fuselage provide to prevent cabin picocell signals coupling to the aircraft antennas (nav/comms systems) and the ground networks?
4. Multiple aircraft factor
   - System design needs to satisfy conditions for terrestrial interference when there are multiple aircraft "in view" of terrestrial networks.

It is only after considering these parameters that a detailed RF link budget analysis can be performed to establish the interference threat to terrestrial networks. In these Comments, QUALCOMM presents a summary of the test and analysis that has been completed in defining these parameters and using them in a system design which includes a detailed RF link budget analysis.

III. Interference from Terrestrial Systems

Anticipating that in-cabin systems would operate in the same spectrum bands allocated to terrestrial service providers, one of the earliest research projects pursued by QUALCOMM was quantification of interference from networks and phones on the ground to the in-cabin system. Any interference from ground systems reduces receiver sensitivities onboard the aircraft, compromising link budgets and constraining system design. Furthermore, if passenger phones or PC cards are capable of acquiring terrestrial networks, this will potentially delay their acquisition of the in-cabin network in flight and may result in registration attempts through a series of access probes increasing in amplitude up to maximum power.

Measurements were made over the course of ten flight legs across the continental U.S. and up and down the West Coast aboard QUALCOMM corporate aircraft. On each flight, a test setup capable of measuring the signal levels received from terrestrial mobile and base stations in the PCS and Cellular bands was used. All measurement antennas were mounted at the center of the aircraft windows in the passenger cabin. Logs were also collected from CDMA phones that continuously searched the standard Cellular and PCS band channels and attempted acquisition. Based on GPS records during the flights, data were segmented by altitude phases to separate the ground and takeoff/landing phases from the cruising phases of flight. Statistics of received forward link power, Pilot Ec/Io (for successful acquisitions), and reverse link power were compiled from the flight data.

Median forward link power at altitudes greater than 10,000 feet was -70 and -88 dBm for Cellular and PCS band respectively. 90^{th} percentile power was -65 and -81 dBm for Cellular and PCS band, see **Figures 1 and 2**.

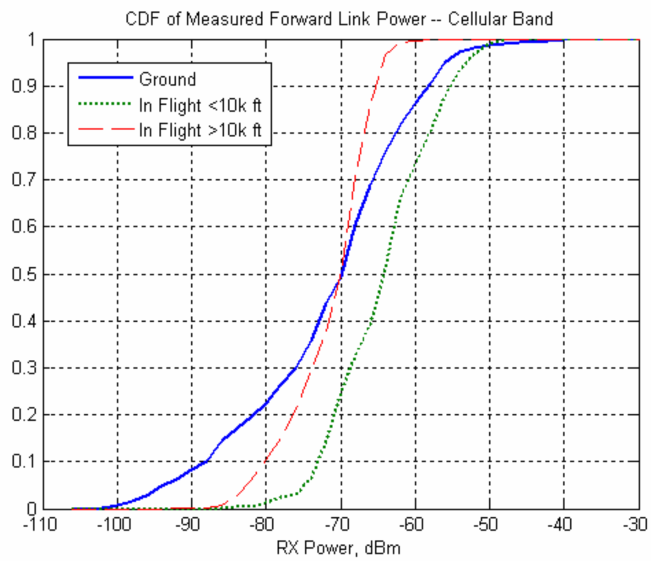

Figure 1: CDFs of measured forward link power per CDMA channel in the Cellular band

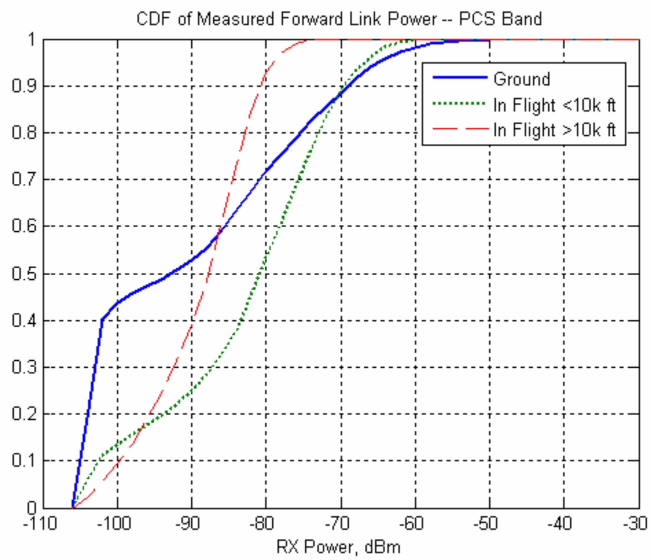

Figure 2: CDFs of measured forward link power per CDMA channel in the PCS band

At altitudes greater than 10,000 ft, median power received per 1.25 MHz CDMA channel in the mobile transmit band was -94 and -96 dBm in Cellular and PCS bands respectively. 90th percentile power was -92 and -94 dBm respectively. Note that these measurements may represent the combined power from multiple devices across multiple standards. No attempt was made to separate TDMA/GSM signals from CDMA signals. **Figure 3 and Figure 4** present distributions of the CDMA channel power received from terrestrial mobile handsets in the PCS and Cellular bands. Focusing on the median values of the curves one would expect at least 6 to 7 dB between the Cellular and PCS cases due to propagation frequency property differences. This is not apparent from the curves. This is because the majority of the measurements were made near the noise floor of the spectrum analyzer which reduces the number of samples that could have been taken for the PCS case. This results in a compression of the distribution curve skewing the difference between the Cellular and PCS curve.

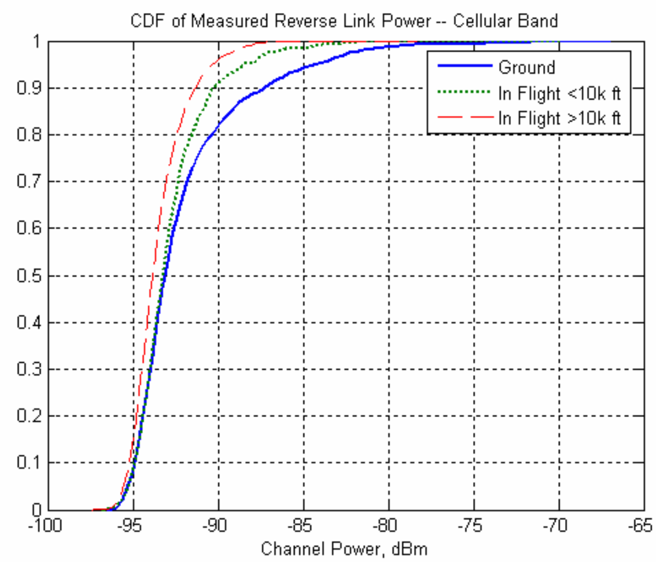

Figure 3: CDFs of measured reverse link power per CDMA channel in the Cellular band

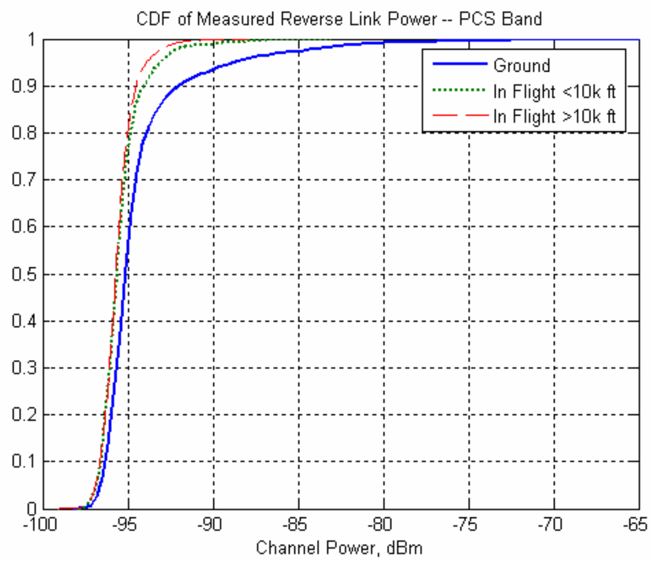

Figure 4: CDFs of measured reverse link power per CDMA channel in the PCS band

Figure 5 and 6 show distributions of the pilot channel Ec/Io for time instances where the mobile acquired the terrestrial system's pilot channel. At altitudes greater than 10,000 feet, overhead channels from terrestrial forward links were successfully acquired in 5.9% of Cellular band attempts and in 4.1% of PCS band attempts. For comparison, ground segment acquisition success rates were 24.3% for Cellular band (essentially indicating that one of the four principal channels was active) and 8.5% for PCS band. Unfortunately, it is impossible to distinguish which acquisition failures were due to poor signal conditions, and which were due to the absence of a CDMA system in the channel under test. During this test the phone was limited to scanning the four principal channels used in the Cellular band.

Focusing on the median of the distribution there is 1 dB higher Ec/Io in the PCS case than that for the Cellular case in the cruise segment (above 10,000). Ec/Io in the PCS case is 3 dB higher than that for the Cellular case and this may be attributed to difference in network configurations between PCS and Cellular band wireless providers. It is also worth noting that the received power in the Cellular band was higher than that for the PCS band which indicates a higher Io (denominator) term and hence a lower Ec/Io in the Cellular band assuming the same Ec (numerator) term. If Io included noise from sources other than CDMA base stations, then this would explain the difference in Ec/Io median values between PCS and Cellular bands.

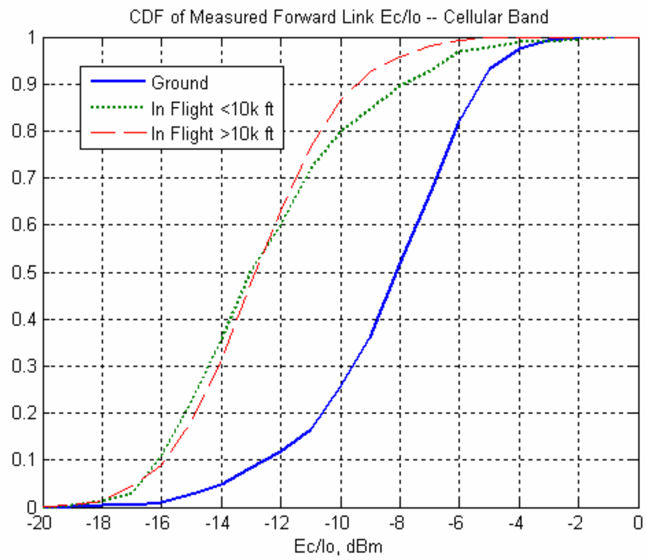

Figure 5: CDFs of measured Pilot Ec/Io in the Cellular band for all successful system acquisitions

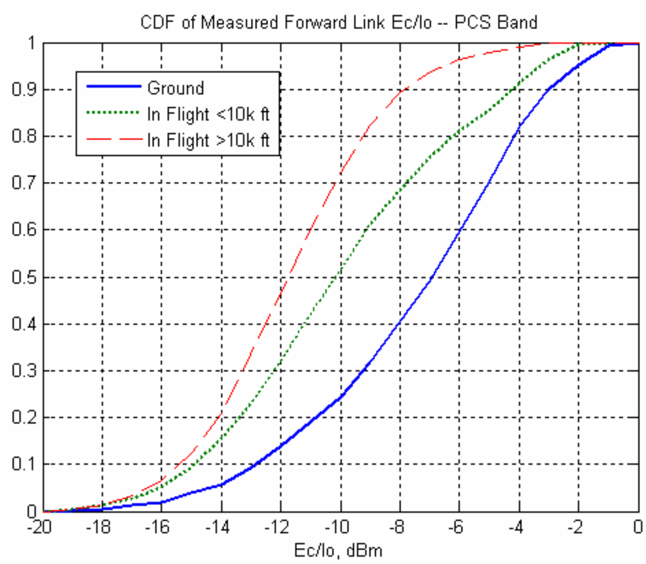

Figure 6: CDFs of measured Pilot Ec/Io in the PCS band for all successful system acquisitions

Prevention of Ground System Acquisition

Once a CDMA handset has acquired the in-cabin picocell, frequency searches are halted, eliminating the chance that a ground network is acquired. The greatest chance of acquiring a ground network is while the phone performs its frequency search immediately after being powered up in flight. Previous tests have shown that if such a link is established, it is highly unstable and will fail within a few seconds in most cases. This indicates that the problem of ground network acquisition is transitional – any acquisition of a ground network only delays the inevitable acquisition of the in-cabin picocell. Any countermeasure aimed at preventing ground acquisitions, such as aircraft shielding, altitude control, or noise floor elevation, will reduce the length of the transitional period and increase the chance that the in-cabin network will be the first one detected. The data collected by QUALCOMM can be used to predict the efficacy of such countermeasures.

For Pilot channel acquisition, the sensitivity level of the typical CDMA phone can be assumed to be -123 dBm. This accounts for thermal noise in the 1.25 MHz receiver bandwidth, a 5 dB assumed receiver noise figure, and a -15 dB Pilot Ec/Io requirement for acquisition. To prevent system acquisition, any countermeasure to increase the loss between the ground and cabin interior will have to reduce the received Pilot channel power to this level[2].

The current flight data consists of parallel measurements of total RX power (from the phone AGC), and Pilot channel Ec/Io, when acquisition was successful. Assuming that the AGC reading represents Io, and that we have an accurate Ec/Io estimate, then for any measurement

[2] QUALCOMM has used a value for Ec/Io of -15dB based on IS95 phone designs. However, it should be noted that for phones designed in accordance with CDMA 2000 1x standards an Ec/Io value of -17dB should be used. In order to prevent successful pilot demodulation an Ec/Io value of -20dB should be considered as the design goal.

point, we can express the required additional shielding (or other countermeasure) to prevent acquisition as:

(Ec/Io) + AGC - Sensitivity (all in dB)

which is termed the “pilot margin.”

If the pilot margin is considered across all measurements, it can help predict how effective a given level of shielding will be, i.e. what percentage of our pilot acquisitions would have been blocked**. Figure 7** shows the cumulative distribution of pilot margin at altitude greater than 10,000 ft for both Cellular and PCS bands. For measurements where the system was not acquired, pilot margin was assumed to be zero (i.e. no countermeasure required to prevent acquisition). The steep rise in the distribution at zero indicates that approximately 95% of all acquisition attempts were unsuccessful. **Figure 8** shows a close-up of the distribution for margins > 0 dB.

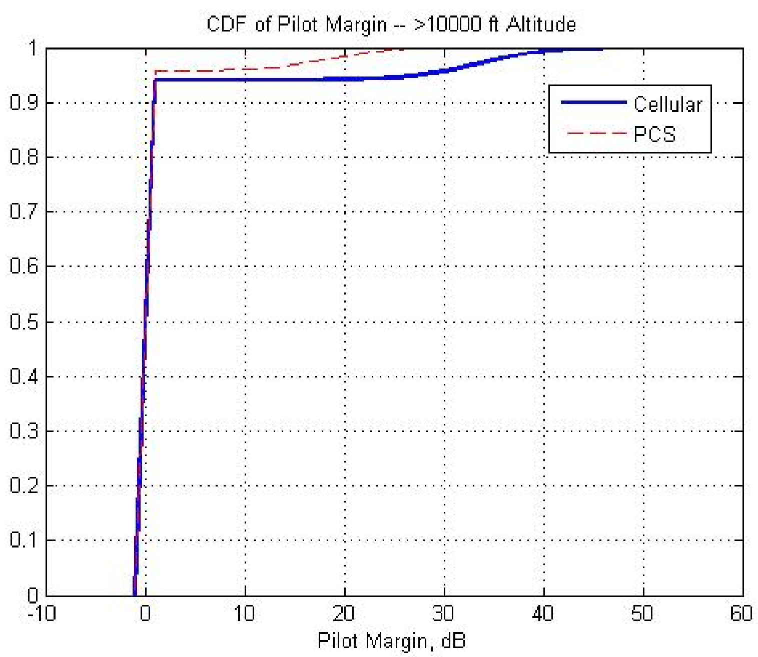

Figure 7: CDF of pilot margin for all measurements at altitude greater than 10,000 feet

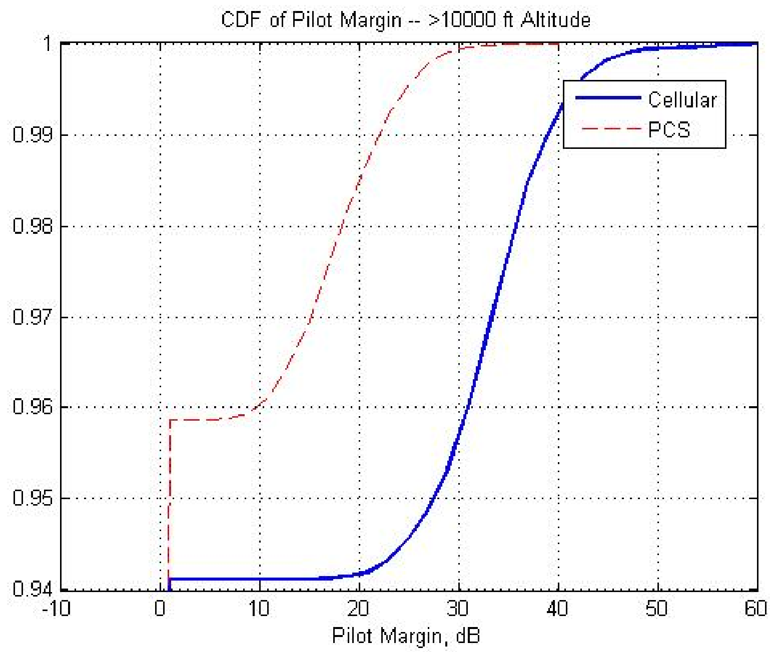

Figure 8: Close-up of right-hand tail of CDF shown in Figure 7

These figures can also be interpreted as showing the predicted system acquisition failure rate as a function of cabin shielding (or other countermeasure). **Figure 8** in particular allows us to predict the efficacy of any proposed countermeasure. For example, 20 dB of shielding would increase the PCS-band acquisition failure rate to approximately 98.5%, but would have negligible effect on Cellular-band acquisitions. The point of diminishing returns for Cellular band shielding appears to occur at approximately 35 dB of shielding. **Figure 8** suggests that approximately 50 dB of shielding would be required to eliminate completely the chance of Cellular system acquisition,

Ground interference imposes limitations on the link budget margin available for an in-cabin picocell based wireless communication system, but a reliable link can still be established within the cabin given the short range of the communication link. The ground interference values reported in this section were based on the power measured inside the aircraft cabin, but it is important to note that these measurements represent all available PCS or Cellular channels. It follows that the ground interference value is only of concern when the in-cabin channel and the ground channels coincide. Since this occurs for only a fraction of the flight duration, the susceptibility to this ground interference is small but must nevertheless be accounted for in any in-cabin system design.

Ground Network Acquisition Statistics for Typical Commercial Devices

To better characterize the behavior of commercial CDMA handsets during in-flight conditions, QUALCOMM collected logs from an idle-mode phone activated on Verizon Wireless' nationwide network at cruising altitude during a cross-country flight from San Diego to New Jersey on QUALCOMM's Corporate aircraft. The phone was suction cup mounted at the center of the aircraft passenger window. A total of 9834 frequency searches were performed by the handset over the course of the flight, of which 9.6% resulted in successful acquisition of CDMA overhead channels. In most of these cases, the phone subsequently attempted registration, resulting in additional delay before the next frequency search. **Figure 9** shows the cumulative distribution of the delay between frequency searches following a successful system acquisition. Median delay was 8.5 seconds; 95th percentile delay was 25.3 sec. In comparison, the mean time interval between failed acquisitions was 800 ms.

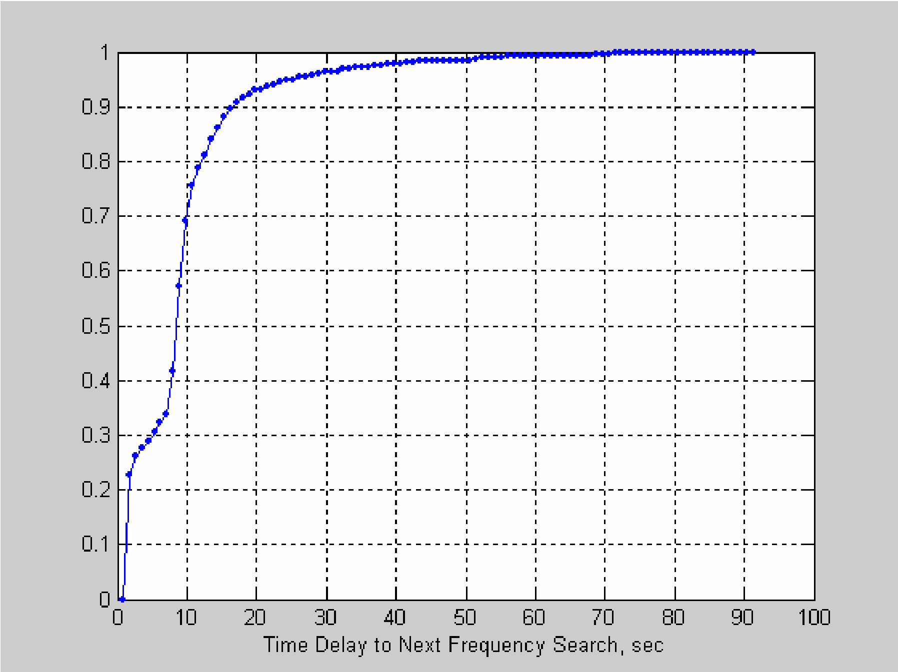

Figure 9. Cumulative distribution of time delay to next frequency search after successful acquisition of a ground network, from Verizon phone on cross-country flight.

Looking across all acquisition attempts (successful and failed), there was an 8% of chance of a 5 sec delay; a 3.2% chance of a 10 sec delay, and a 0.1% chance of a 60 sec delay. The cause of the longest delays is still under investigation, but appears to be related to the phone occasionally entering a low-power slotted mode.

Countermeasures

These results help characterize the transitional period that occurs when handsets are first powered up in flight in the presence of an in-cabin picocell. If a phone successfully acquires a terrestrial network (which occurred in 9.6% of all observed frequency searches), these measurements indicate the probability of the additional delay associated with that search. Any countermeasure to shorten this transition period must either 1) increase the chance that the in-cabin system will be searched early or 2) decrease the chance of a terrestrial network being detected if its frequency is searched by a phone in flight.

Measures to Favor Early Searching of In-Cabin Network

Countermeasures in this category consist principally of interaction with the roaming behavior of the CDMA device. It is recommended that the in-cabin network possess a unique SID/NID to distinguish it from terrestrial networks. For users that subscribe to in-cabin service, the preferred roaming list must be updated to contain the SID and NID of the onboard network. Ideally, the onboard system should be specified as a "preferred" system in the roaming list, and be positioned in the list to ensure that the phone searches for it soon after powering up.
The in-flight system can also be operated at a channel likely to coincide with phones' "most recently used" list, based on the flight's city of origination. This increases the probability that the in-cabin network will be one of the first searched by the phone upon power-up. However, in this case, the acquisition record for that SID/NID must contain all possible channels on which an in-cabin network might be operated.

These strategies were used effectively during the joint American Airlines/QUALCOMM proof-of-concept demonstration to speed the acquisition time for Sprint PCS users participating in the demonstration.

Measures to Avoid Detection of Terrestrial Networks

Countermeasures in this category include RF shielding of the aircraft or allowing in-cabin phone use only at higher cruising altitudes. System developers in the European Community have investigated potential solutions which involve elevating the noise floor of in-cabin receivers.

IV. Interference to Ground Networks

During collaborative aircraft compatibility testing with Boeing in April 2004, measurements were made external to the grounded aircraft while an in-cabin network was operated. A CDMA picocell system was installed on the aircraft in a dual-sector, receive diversity configuration. **Figure 10** shows the placement of 100 commercially available CDMA handsets that were distributed evenly throughout the passenger cabin and flight deck of the single aisle MD-90 aircraft.

Figure 10. CDMA phone placement in MD-90

Two test cases were investigated for both Cellular and PCS bands: 1) All phones in simultaneous Markov calls with the in-cabin picocell; 2) All phones manually set to full-power transmission, as a "worst-case" scenario. Forward and reverse link signal strength was measured exterior to the aircraft out to a range of approximately 1 km.

Major findings of this investigation were:

- The accumulated power from 100 phones operating at maximum output was still strongly detectable at a range of 1.0 kilometers for both frequency bands.
- Little signal power was observable beyond a range of approximately 200 meters from 100 phones transmitting at power levels controlled by a picocell.

- Power detected from the CDMA power-controlled handsets was typically 60-80 dB lower than the handsets operating at full power.
- Beyond a distance of 550 meters, a CDMA handset was unable to detect the picocell's forward link.

In particular, the obvious disparity between phone emissions with and without power control was extremely useful for demonstrating the unique and beneficial properties of CDMA power control. The implications for prevention of interference to both ground networks and avionics receivers were clear from this testing.

This work is described in more detail in the QUALCOMM/Boeing document, "*Electromagnetic Compatibility between Boeing MD-90 Aircraft and CDMA Mobile Phones Test Report*," 80-3490-1. The issue of interference to ground networks is also addressed analytically in the subsequent section on in-cabin network design. This document can be downloaded via the following link: ftp://ftp.qualcomm.com/pub/outgoing/RTCA/80-H3490-1_B.pdf

V. In-Cabin Network Design

This section summarizes our recent work on system design for an in-cabin CDMA network. Many of the inputs to the following link budgets are based on testing performed by QUALCOMM over the past two years.

System Design Constraints and Assumptions

Any in-cabin network is subject to the following three fundamental design constraints for both the forward and reverse links:

- In-band and out-of-band emissions from in-cabin picocell and phones must not interfere with avionics equipment.

- Total transmitted power (picocell or combined phone EIRP) inside the cabin must not cause significant degradation to terrestrial mobile and base station receivers.
- Transmitted powers inside the cabin must be sufficient to overcome interference from terrestrial networks and phones (CDMA + all others).

With respect to passenger handsets, the first constraint related to interference to avionics equipment is the subject of ongoing work by RTCA Special Committee 202, in which QUALCOMM is an active participant. The guidelines published by SC-202 will permit airlines and aircraft manufacturers to evaluate objectively whether an installed in-flight system meets this requirement. Furthermore, the picocell system and air-to-ground backhaul equipment is subject to FAA certification, since it is installed permanently onboard the aircraft.

To meet these three constraints, there are only a limited number of design parameters available. Due to reverse link power control, phone transmissions during traffic channel operation are governed largely by the RF path loss between the handset and the picocell receiver input. Relevant design parameters are base station antenna placement, use of multi-sector/diversity networks, and use of distributed antenna systems (or leaky feeder antennas). Phone transmissions during access channel operation can be limited via access parameters advertised by the picocell. In addition to managing path loss to limit forward traffic channel power, forward link power can be optimized by limiting total maximum picocell EIRP, the power allocated to the CDMA overhead channels, and the maximum power allocated to any single traffic channel.

The second constraint above represents an upper bound at which in-cabin devices can transmit. For the forward link, this represents combined power from all picocells aboard all aircraft within propagation range of a potential victim device on the ground. For the reverse link, this represents combined power from all mobiles aboard all aircraft within range of a potential terrestrial victim base station. As an initial estimate for our system designs, we have assumed an interference power level sufficient to elevate a receiver's effective noise floor by 1.0 dB. Use of the 1 dB value is for the purpose of theoretical analysis only. QUALCOMM does not advocate the 1 dB value—this is simply an assumed figure that a number of companies have used in link budget analysis submissions to the standards organizations such as 3GPP GERAN. The link budget analysis will adjust accordingly based on use of a different interference threshold.

In fact, as discussed below, QUALCOMM believes that an airborne CDMA network can be designed to meet interference threshold less than 1 dB. QUALCOMM believes that the terrestrial carriers, the companies who operate the terrestrial networks on their licensed spectrum, should decide whether to accept such interference in exchange for the revenue generating opportunities presented by the airborne use of mobile devices. As QUALCOMM has maintained in a host of other Commission proceedings, QUALCOMM strongly believes that terrestrial carriers should not be forced to accept interference on an involuntary basis—no one should gain free access to a carrier's spectrum.

Accordingly, for comparison purposes only, QUALCOMM has assumed the same 1 dB threshold value used in prior industry analyses. However, QUALCOMM defers to each terrestrial carrier to determine if there is a level of interference it would be willing to accept in exchange for the revenue generating opportunities from the onboard use of mobile phones and other wireless devices.

Based on our models, a 1 dB threshold value corresponds to -114 dBm (per 1.25 MHz) for a CDMA receiver and -122 dBm (per 200 kHz) for a terrestrial GSM receiver. This assumes the receiver noise floor = Thermal + Rx Noise Figure. The thermal noise power at a terrestrial receiver was calculated based on a receiver noise figure of 5 dB[3], therefore thermal (-174dBm/Hz) + Bandwidth correction (61dBHz) + noise figure (5 dB) = -108 dBm per 1.25 MHz. From the graph in **Figure 11,** an interference power level 6 dB below the receiver noise floor will result in a 1 dB desense of the receiver and so in this example the maximum interference level that can tolerated by a CDMA terrestrial network from the combined power of all mobiles on all aircraft operating picocell networks is -114 dBm (per 1.25 MHz) EIRP. Using the graph shown in **Figure 11**, the link budgets presented in the following section can be modified by using the maximum interference level that is derived from interference thresholds other than the 1 dB example.

Given the closed loop power control feature and minimum output power floor inherent in CDMA technology, QUALCOMM is confident that an airborne CDMA network can be designed to comply with interference thresholds less than the 1dB example. The complexity of the aircraft cabin picocell antenna subsystem, the aircraft shielding effectiveness and the altitude at which the CDMA airborne service can be offered are the variables which need to be carefully addressed when designing for interference thresholds less than 1 dB.

[3] The 5 dB noise figure used in the analysis is representative of older systems and so it should be noted that the current infrastructure equipment have advertised noise figures of 3 dB.

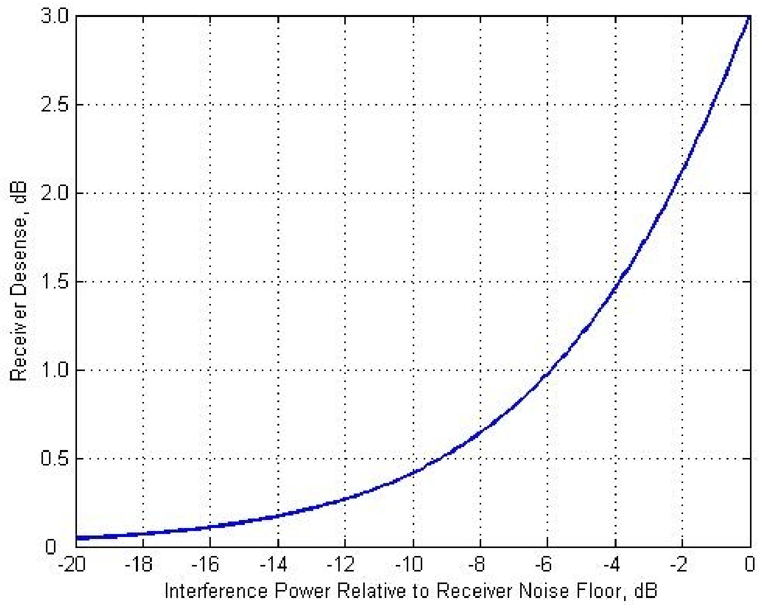

Figure 11. Interference Power (relative to noise floor) versus Receiver Desense

The third constraint represents a lower bound at which in-cabin devices may transmit. Our assumptions in this area are based on the in-flight measurements described in **Section III**. In our link budgets, we use the 90th percentile powers measured in both the mobile transmit and receive bands as the representative interference level from networks and phones on the ground.

Link Budgets

With the second and third constraints in mind, we have constructed link budgets for a hypothetical in-cabin network. Other relevant system assumptions include:

- Network operates in US PCS Band (1900 MHz)
- Aircraft Altitude = 3000 m AGL
- Multiple Equipment Factor (MEF) = 10 dB (10 simultaneous calls)
- Interference from ground: -81 dBm from BTSs; -90 dBm from phones. Based on 90th percentile of QC in-flight measurements

- “Multiple Aircraft Factor” = 0 dB
    - No accounting for multiple aircraft interfering with ground
- In-cabin fade margin = 20 dB
    - Required to account for multipath fades
    - QUALCOMM performed on aircraft measurements and determined that similar fade depths exist for both patch antennas and leaky coax
    - Multiple sector design mitigates this significantly
- Aircraft Penetration Loss = 0 dB (aircraft provides zero RF shielding)
- All antenna gains average out to isotropic

Table 1 presents a forward link budget for a hypothetical in-cabin network. This budget suggests that to meet all design constraints, a maximum path loss of 62.7 dB from picocell to phone is allowable. For a single-sector network, this path loss corresponds to a maximum distance of approximately 12 meters, based on our previous measurements of in-cabin RF propagation. This simple system design is sufficient to provide coverage to a substantial portion of the passenger cabin of a typical medium-haul aircraft, such as the MD-80. For the demonstration conducted by QUALCOMM with American Airlines last year, a dual-sector design was used with largely overlapping sectors. The fading and shadowing mitigation afforded by this design allowed adequate coverage of the entire aircraft cabin within a significant margin.

Table 1. Forward Link Budget for Hypothetical In-Cabin Network

	Value	Units	Calc
Ground Phone Susceptibility (CDMA)	**-114.0**	**dBm**	**A**
Path Loss to Ground (3000 m altitude)	**107.7**	**dB**	**B**
Aircraft Penetration Loss	**0.0**	**dB**	**C**
Multiple Aircraft Factor	**0.0**	**dB**	**D**
Max Allowable Picocell EIRP	**-6.3**	**dBm**	**E=A+B+C-D**
Max Traffic Fraction Per User	**0.2**		**F**
Max Per User EIRP	**-13.3**	**dBm**	**G=E+10*log(F)**
LINK TO AIRBORNE MOBILE			
90%ile Interference from Ground	**-81.0**	**dBm**	**H**
Required Chip SNR for FL CDMA 9.6 kbps in 1.25 MHz	**-15.0**	**dB**	**I**
Effective Receiver Sensitivity	**-96.0**	**dBm**	**J=H+I**
Maximum Fade + Path Loss + Absorption Loss	**82.7**	**dB**	**K=G-J**
Fade Margin	**20.0**	**dB**	**L**
Additional In-Cabin Absorption Loss	**0.0**	**dB**	**M**
Maximum Path Loss (Pico to Mobile)	**62.7**	**dB**	**N=K-L-M**

Figure 12 shows the power distribution in the cabin of a single aisle aircraft configured with a dual sector CDMA 1x picocell and two patch antennas mounted either side at the front of the cabin. The power levels shown represent the mobile phone received power from the picocell network and the phone transmissions. The measurements were performed at a selected number of

seats and at each seat the phone was moved to different positions from floor level to above seat level while the data from the phone was continuously logged. Under picocell control the CDMA mobile phones receive power control messaging at 800 times a second resulting in extremely low transmit powers as the phones maintain connection to the close proximity picocell base station. If necessary a multiple antenna system or leaky coax antenna could be used to control all phones within the cabin to their minimum transmit level of -50 dBm.

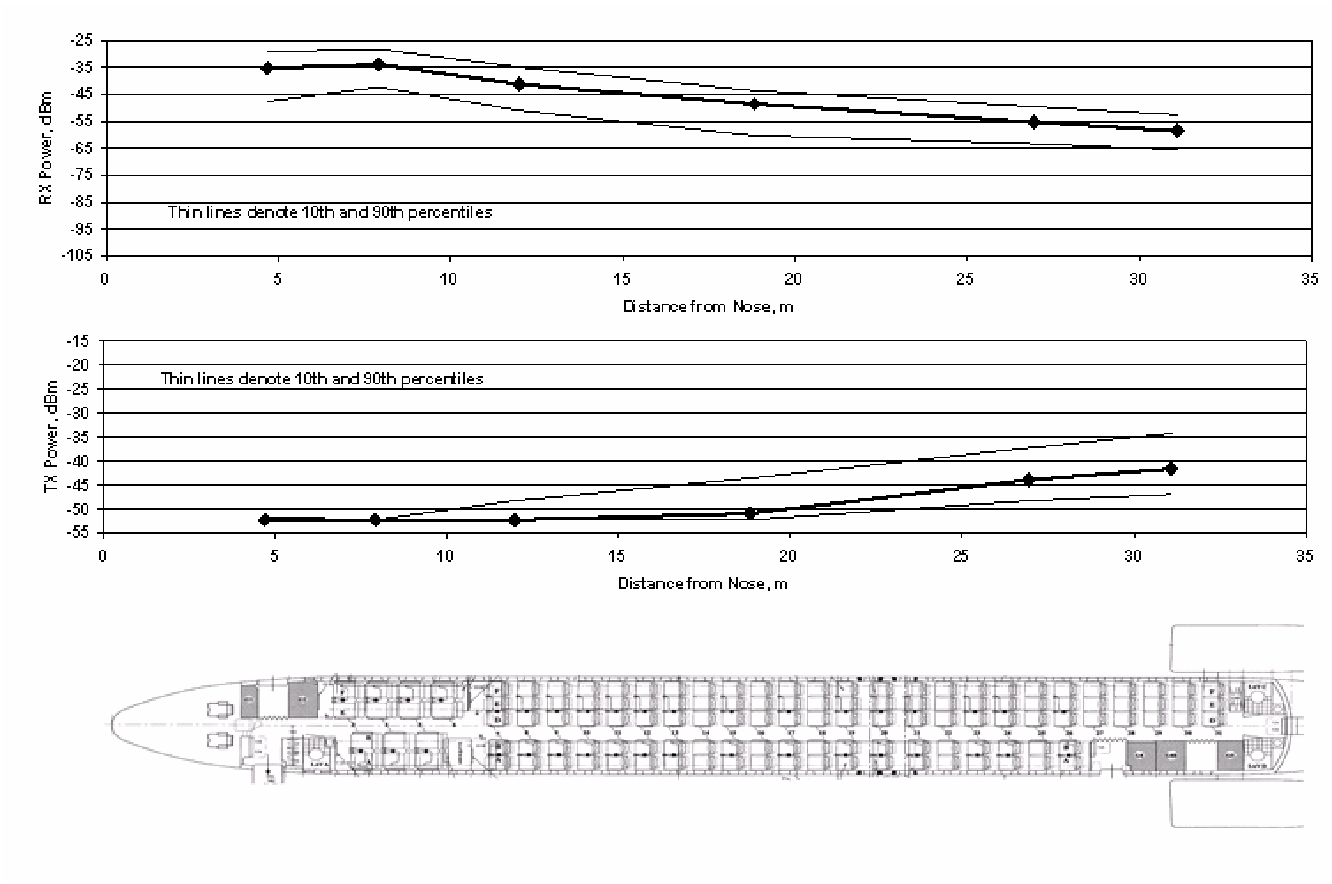

Figure 12. Distribution of Rx and CDMA phone Tx power along the aircraft length

Table 2 presents a reverse link budget for a hypothetical in-cabin network. This budget suggests that to meet all design constraints, a maximum path loss of 68.7 dB from phone to picocell is allowable. For a single-sector, non-diversity network, this path loss corresponds to a maximum distance of approximately 19 meters, based on our previous measurements of in-cabin

RF propagation. This is a slightly more favorable budget than the forward link, but essentially equivalent. As with the forward link, this budget benefits significantly from a multiple antenna design. For the American Airlines demo, the MD-80 cabin was covered adequately using a dual-antenna receive diversity system.

Table 2. Reverse Link Budget for Hypothetical In-Cabin Network

	Value	**Units**	**Calc**
Ground BTS Susceptibility (CDMA)	**-114.0**	**dBm**	**A**
Path Loss to Ground (3000 m altitude)	**107.7**	**dB**	**B**
Aircraft Penetration Loss	**0.0**	**dB**	**C**
Multiple Aircraft Factor	**0.0**	**dB**	**D**
Total Allowable EIRP from Aircraft	**-6.3**	**dBm**	**E = A+B+C-D**
Multiple Equipment Factor	**10.0**	**dB**	**F**
Max Allowable EIRP from Single Mobile	**-16.3**	**dBm**	**G = E-F**
LINK TO AIRBORNE MOBILE			
90%ile Interference from Ground	**-90.0**	**dBm**	**H**
Required Chip SNR for RL CDMA 9.6 kbps in 1.25 MHz	**-15.0**	**dB**	**I**
Effective Receiver Sensitivity	**-105.0**	**dBm**	**J = H+I**
Maximum Fade + Path Loss + Absorption Loss	**88.7**	**dB**	**K = G-J**
Fade Margin	**20.0**	**dB**	**L**
Additional In-Cabin Absorption Loss	**0**	**dB**	**M**
Maximum Path Loss (Pico to Mobile)	**68.7**	**dB**	**N = K-L-M**

VI. <u>Remaining Development Tasks</u>

Sections III, IV and V highlight the significant progress made to date investigating the design and feasibility of an airborne mobile phone system. This section outlines the development tasks that QUALCOMM has identified for future work in this area.

Developing a Mechanism to Prevent Terrestrial Network Acquisition

Section III discusses potential countermeasures to prevent acquisition of terrestrial networks while in flight. The final mechanism must address both the transitional period when passengers' phones are first powered up in the presence of the in-cabin network and the cruise phase of flight. Modifications to existing preferred roaming lists supplied by U.S. CDMA carriers will be tested under both laboratory and in-flight conditions. RF-based solutions such as aircraft hardening and noise floor elevation will be tested in conjunction with industry partners to evaluate their relative efficacy, practicality, cost-effectiveness, and cross-technology compatibility.

Validation of Ground Interference Assessments from CDMA Airborne Network

To date, evaluation of potential interference to terrestrial mobile networks has been based on link budget analysis incorporating assumptions about aircraft penetration losses and other variables. Attempts to measure air-to-ground interference experimentally have been inconclusive to date. Assumption of a transparent aircraft is likely appropriate for the reverse link, where a passenger's handset can be positioned immediately adjacent to an aircraft window. However, the picocell forward link may be subject to significant attenuation since those antennas are typically positioned more centrally within the cabin. This topic is a point of contention between various interested parties and has a significant impact on both the engineering and regulatory aspects of this research and development work.

QUALCOMM proposes to perform further ground-based aircraft testing in conjunction with industry partners to evaluate the characteristics of signal leakage from aircraft cabins. In particular, the interaction between gain patterns of picocell antennas (directional patch or leaky feeder) and the various apertures in the aircraft fuselage will be evaluated more in depth.

Finally, flight tests to measure aircraft-to-ground and ground-to-aircraft propagation will be conducted under well-controlled conditions to validate our analyses and ground-based measurements. Aircraft position and orientation with respect to the ground measurement site must be carefully accounted for during all tests.

Multi-technology Cabin Network Design

There is general agreement that any in-flight system implemented for use in the U.S. must support both cdma2000 1X and GSM at a minimum. It is likely that other technologies such as 1xEV-DO, 802.11a/b/g and WCDMA will be supported at some point. These multi-technology systems pose unique design challenges which require further research, development, and testing.

Interoperability

With respect to installation on the aircraft, it is desirable that these systems operate in close physical proximity to each other and potentially share antennas for in-cabin RF coverage. Consequently, system designs must account carefully for adjacent channel interference and inter-technology interference. Acceptable levels of receiver desensitization will be determined, considering performance specifications and known interference sources internal and external to the aircraft.

RF Intermodulation Evaluation

The unique combination of transmitters in such multi-technology designs will create intermodulation products that potentially fall within the receive bandwidths of in-cabin communication systems as well as avionics receivers. QUALCOMM intends to conduct an analytical study of possible multi-technology systems that considers multiple permutations of transmit channels and predicts the location of significant intermodulation products. Specific channel combinations and spacings which pose interference risks will be identified to produce general design guidelines for system implementers.

Validation of Compatibility with Aircraft Systems

Aircraft safety remains the focus of QUALCOMM research efforts and so we will continue to support RTCA SC-202's work to evaluate compatibility between transmitting passenger electronic devices and aircraft avionics. This includes participation in collaborative testing with consumer equipment manufacturers, aircraft manufacturers, avionics equipment manufacturers, airlines, and research groups from government and academia.

VII. Mobile Devices Beyond Voice

QUALCOMM recognizes the social issues associated with voice services on board a commercial aircraft but would like to point out that the introduction of voice services on board commercial aircraft is not paced by the introduction of mobile phone service. There are commercial airlines operating today with wireless networks onboard that provide all subscribing passengers with the ability to make VoIP calls via their carry on devices.

QUALCOMM would also like to highlight the fact that today's mobile phone has many capabilities beyond basic voice and with the introduction of 3G networks have become the "convergent device" offering many non-voice services. See **Figure 13.**

Figure 13. The Mobile Phone is the "Convergent" Device

When considering the use of mobile phones on board aircraft, the following scenarios must be considered:

- Mobile Phone – Wireless Disabled
    - Off-Line games
    - Playback stored music (MP3 Player)
    - Playback stored video clips
    - Playback stored news articles
    - Personal Organizer
    - Camera
    - Message creation and store
- Mobile Phone – Wireless Enabled (Broadband Aircraft to Ground Link)
    - Voice Communications
    - Data Communications
    - SMS, Internet, email, video conferencing
    - On-Line games (multi player gaming inside aircraft and off aircraft)
    - Music, games, pictures and video downloads
    - Entertainment, news, sports, weather and finance updates
    - Movie Guides, Restaurant Guides, Destination Information
    - Live TV

VIII. Conclusion

QUALCOMM is pleased to provide a technical summary of the work that has been completed to date and looks forward to participating in collaborative efforts with the terrestrial service providers, aviation industry and Government agencies to fully evaluate the potential for providing airborne mobile phone services.

Respectfully submitted,

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